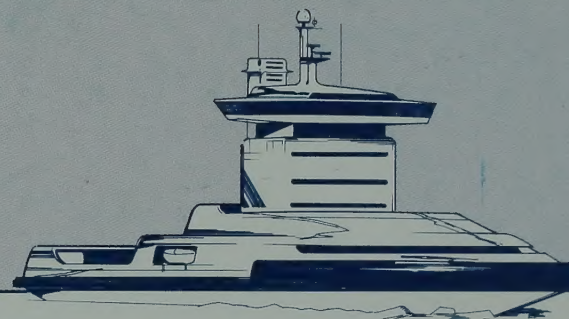


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**WÄRTSILÄ**

Gustav Lindqvist  
Stefan Gordin

# **DESIGN FOR A NOVEL ICEBREAKER ASSISTING ARCTIC LNG VESSELS**

## Introduction

THIS PAPER DESCRIBES THE DESIGN OF A NEW HIGH-POWERED ARCTIC ICEBREAKER. THE ICEBREAKER IS PLANNED AS AN ESCORT FOR ONE OR TWO ARCTIC 165,000 m<sup>3</sup> LIQUEFIED NATURAL GAS SHIPS (ALNGS). THESE TANKERS ARE UNDER STUDY AS A MEANS OF TRANSPORTING PRUDHOE BAY GAS DOWN TO SOUTHERN MARKETS, EITHER DIRECTLY OR BY TRANSHIPMENT IN THE ALEUTIAN ISLANDS.

THESE SHIPS, THE ESCORT AND ALNGS, ARE BEING DEVELOPED FOR ARCO (THE ATLANTIC RICHFIELD CO.), ONE OF THE MAIN OWNERS OF THE NORTH SLOPE ALASKA GAS. ARCO IS NOW SERIOUSLY INVESTIGATING DIFFERENT WAYS TO GET THE ALASKA GAS MOVING. THE TWO MAIN ALTERNATIVES ARE PIPELINE AND MARINE TRANSPORTATION. PIPELINES ARE FAVOURABLE AT HIGH OUTPUTS, BUT THE MARINE SYSTEM MAY BE BETTER WHEN THE OUTPUT IS LOW. THE INVESTMENT IS SMALLER AND THE SYSTEM IS FLEXIBLE, AS THE OUTPUT CAN BE INCREASED IF CONSUMPTION RISES OR MODIFIED TO ACCORD WITH GEOGRAPHICAL CHANGES IN CONSUMPTION PATTERNS.

THE INTERESTING ASPECT OF THIS PARTICULAR MARINE SYSTEM IS THE CONDITIONS IN WHICH IT IS REQUIRED TO OPERATE. IN THE HARSH ENVIRONMENT OF THE BEAUFORT SEA, TEMPERATURES CAN SINK TO ABOUT  $-40^{\circ}\text{C}$  AND THE ICE CAN FORM RIDGES 20 METERS THICK.

THE SHIPS OBVIOUSLY HAVE TO BE STRONG AND POWERFUL. THE ALNGS HAS STEAM TURBINES AND ITS TOTAL SHAFT POWER EXCEEDS 100 MW (140,000 hp). THE LENGTH OF THE SHIP IS ABOUT 360 m, ITS BREADTH IS OVER 49 m AND ITS DRAFT IS 12.8 m.

THE ALNGS WILL BE ABLE TO BREAK ICE MORE THAN 2 METERS THICK AND SHOULD BE CAPABLE OF INDEPENDENT OPERATION IN MODERATE ICE CONDITIONS. THIS TANKER WILL, HOWEVER, NEED A POWERFUL ESCORT ICEBREAKER TO INCREASE ITS AVERAGE SPEED AND SECURE YEAR-ROUND OPERATION.

## Year-round arctic transportation

THE MARINE TRANSPORTATION SYSTEM HAS TO ALLOW YEAR-ROUND OPERATION. THE CONSUMPTION OF ENERGY BY INDUSTRY IS CONSTANT THROUGHOUT THE YEAR AND NATURAL GAS CANNOT EASILY BE STORED NEAR THE CUSTOMERS IN LARGE QUANTITIES.

YEAR-ROUND OPERATION IN THE BEAUFORT SEA IS NOT EASY TO ACCOMPLISH. AT MIDWINTER THE LEVEL ICE IS UP TO 2 METERS THICK AND RIDGING IS FREQUENT. IN SEVERE WINTERS, THERE ARE EVEN CONSIDERABLE AREAS OF MULTI-YEAR ICE.

YEAR-ROUND OPERATION IS A FAIRLY NEW DEVELOPMENT IN NORTHERN SHIPPING. IN THE SUBARCTIC GULF OF BOTHNIA, WHERE THE LEVEL ICE IS ONLY UP TO 1 METER THICK, YEAR-ROUND TRAFFIC STARTED AS LATE AS 1971. HERE ICE-STRENGTHENED CARGO SHIPS ARE ASSISTED BY 16 MW (22,000 hp) SHAFT POWER URHO-TYPE ICEBREAKERS.

TODAY, YEAR-ROUND ARCTIC OPERATION EXISTS ONLY IN THE SOVIET UNION. SINCE 1979 SHIPPING HAS BEEN MAINTAINED THROUGHOUT THE YEAR BETWEEN MURMANSK AND DUDINKA IN THE JENISEI RIVER, WHERE THE THICKNESS OF LEVEL ICE IS AROUND 1.5 METERS. ICEBREAKING SHIPS OF THE FINNISH-BUILT SA-15 TYPE ARE ASSISTED BY SHALLOW-DRAFT ICEBREAKERS OF THE SOROKIN TYPE AND 55 MW (75,000 hp) NUCLEAR ICEBREAKERS OF THE ARKTIKA TYPE.

THE ICE CONDITIONS IN THE BEAUFORT SEA ARE MORE SEVERE THAN THOSE IN THE KARA SEA OUTSIDE DUDINKA. THE PRESENT EXAMPLE, HOWEVER, SUGGESTS THAT YEAR-ROUND TRAFFIC IS FEASIBLE TO AND FROM PRUDHOE BAY. THE ICE PROBLEMS OF THE OVER 80,000 dwt ALNGS ARE ALSO RELATIVELY SMALLER THAN THOSE OF THE 15,000 dwt SA-15 CARGO SHIPS.

ALTHOUGH THE ALNGS CAN BREAK ICE ON ITS OWN, IT STILL BENEFITS FROM ASSISTANCE. DUE TO ITS HUGE MASS, IT CAN EASILY PENETRATE DEEP INTO THICK RUBBLE FIELDS OR MULTI-YEAR ICE FIELDS, BUT IT HAS DIFFICULTY IN STARTING AGAIN ONCE IT HAS STOPPED. THE THRUST OF ITS PROPELLERS ALONE IS MUCH SMALLER THAN THE COMBINED THRUST OF ITS PROPELLERS AND DEACCELERATING MASS. THE ICE RESISTANCE ALSO INCREASES, AS THE STATIC FRICTION FORCE IS GREATER THAN THE DYNAMIC FRICTION FORCE. THE ALNGS CAN ALSO BE IN TROUBLE WHEN THE ICE IS COMPRESSED BY STRONG WINDS.

THE TASK OF THE ESCORT ICEBREAKER IS TO GUARANTEE SUCCESSFUL OPERATION. IT WILL INCREASE THE AVERAGE SPEED OF THE ALNGS BY:

- FREEING THE ALNGS WHEN IT GETS STUCK
- BREAKING A CHANNEL IN WHICH ICE RESISTANCE IS REDUCED
- HELPING THE ALNGS TO CIRCUMNAVIGATE DIFFICULT PATCHES OF ICE
- PUSHING THE ALNGS THROUGH THICK ICE RIDGES

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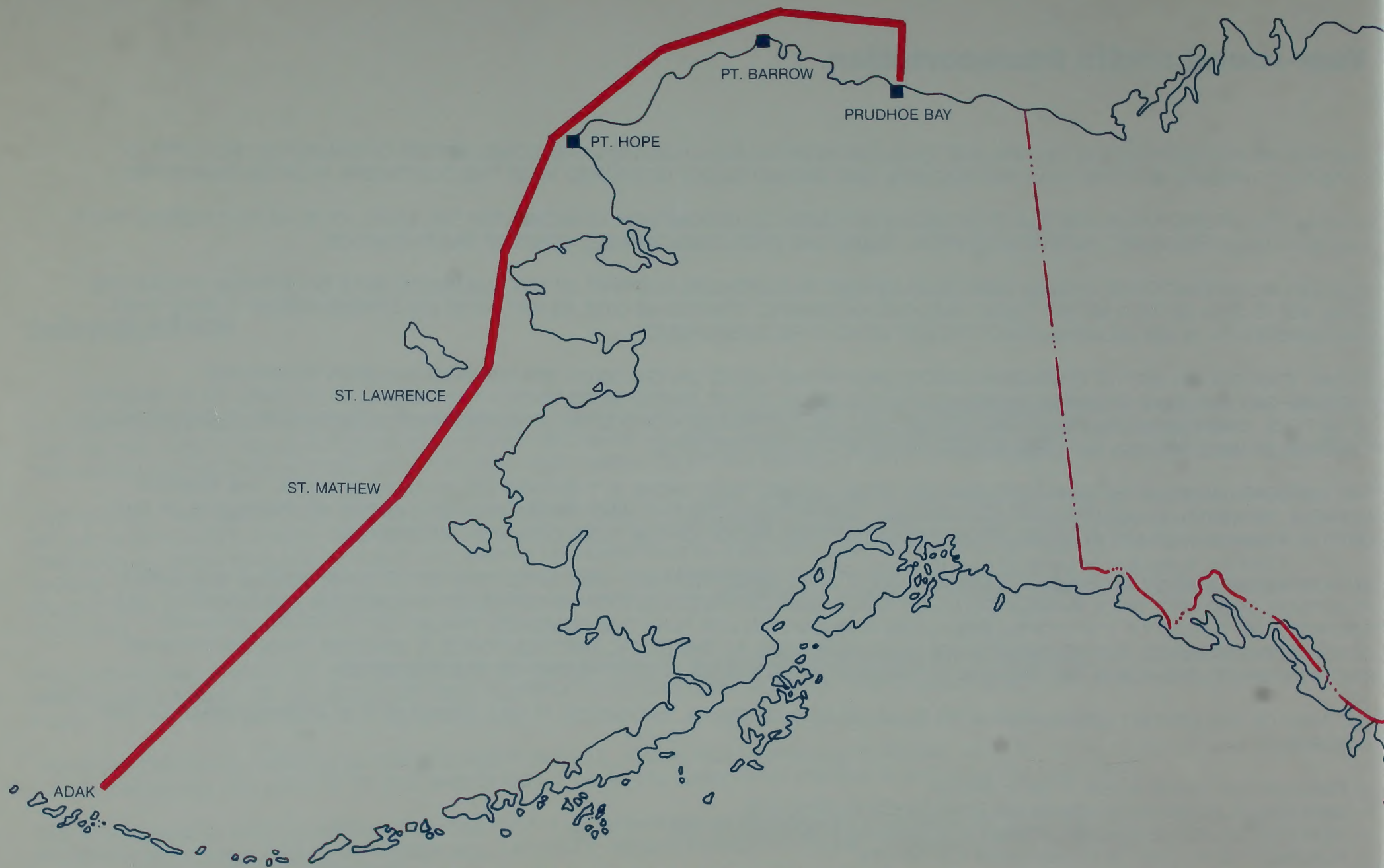


FIGURE 1: ARCTIC TANKER ROUTE PRUDHOE BAY — ADAK.



FIGURE 2: EXISTING AND PLANNED YEAR-ROUND ARCTIC OPERATION.

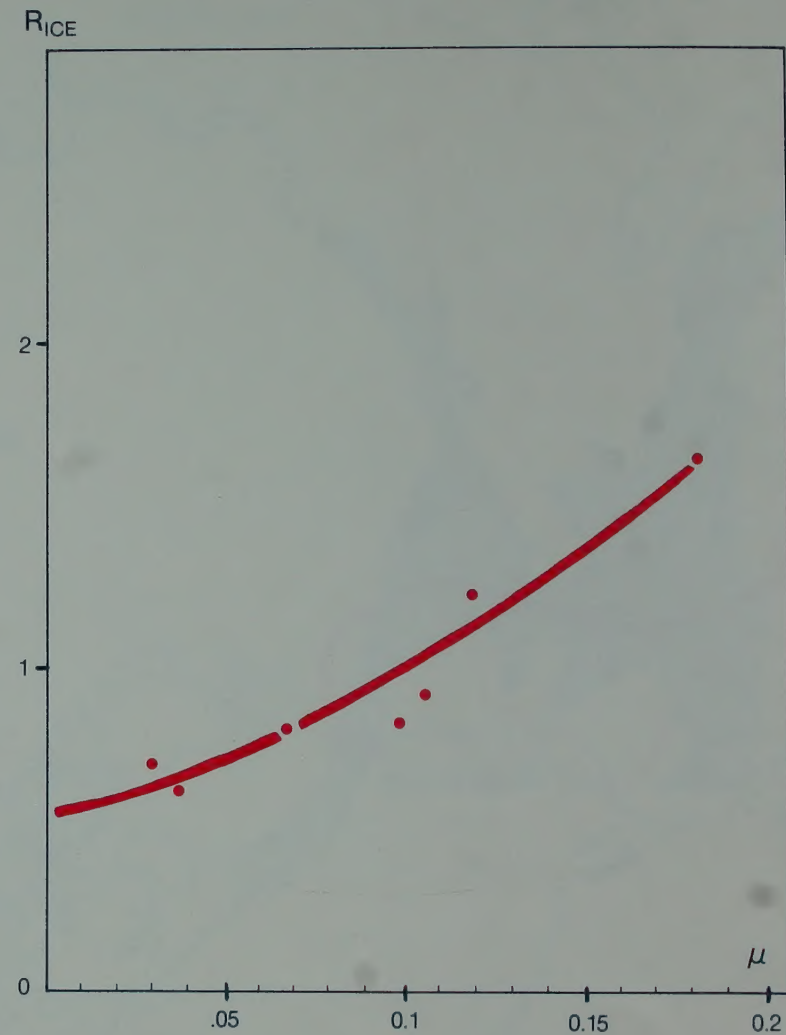
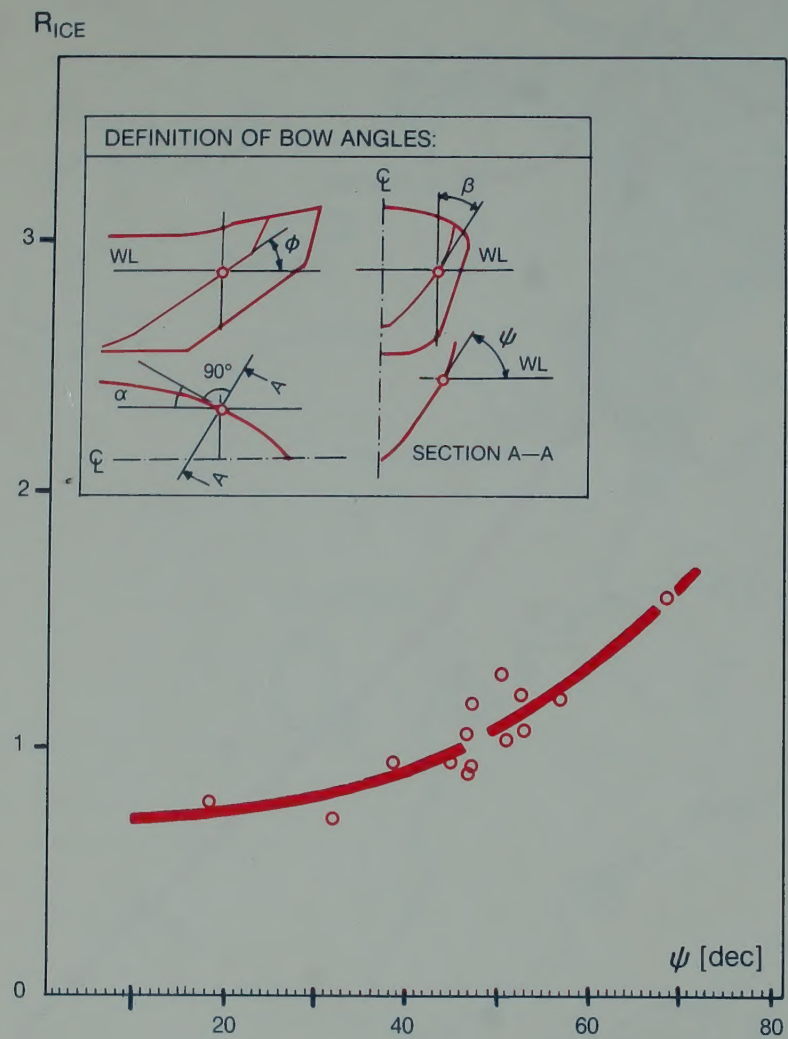


FIGURE 3: MAIN RESISTANCE FACTORS, FORM AND FRICTION.

## **New developments in icebreaking**

ADVANTAGE SHOULD BE TAKEN OF RECENT PROGRESS IN THE ART OF ICEBREAKING, IN ORDER TO OBTAIN OPTIMAL PERFORMANCE AT A REASONABLE COST. GOOD PERFORMANCE IS ACHIEVED WHEN THE ICEBREAKER HAS:

- LOW RESISTANCE
- HIGH THRUST
- GOOD MANEUVERABILITY

IN ALL ICE CONDITIONS, THE RESISTANCE IS AFFECTED BY FRICTION. ALL MEANS SHOULD THEREFORE BE EMPLOYED TO MINIMIZE THIS FACTOR. THE STANDARD PROCEDURE TODAY IS TO COAT THE HULL WITH SOLVENT-FREE EPOXY PAINT. THE RESULT IS A SMOOTH, FAIRLY DURABLE HULL SURFACE. THE PAINT WILL BE WORN OFF IN THE WATERLINE AREA, HOWEVER, DUE TO THE HIGH LOCAL LOAD. IN THE NEW FINNISH ICEBREAKER OTSO, THIS PROBLEM HAS BEEN SOLVED BY USING STAINLESS STEEL COMPOUND PLATING IN THE WATERLINE AREA.

FRICTION CAN ALSO BE REDUCED BY PUMPING WATER ON THE ICE, TO MAKE THE SNOW SLIPPERY, OR BY USING THE WELL-KNOWN AIR BUBBLER SYSTEM.

FIGURE 3 SHOWS THE EFFECT OF FRICTION IN MODEL SCALE.

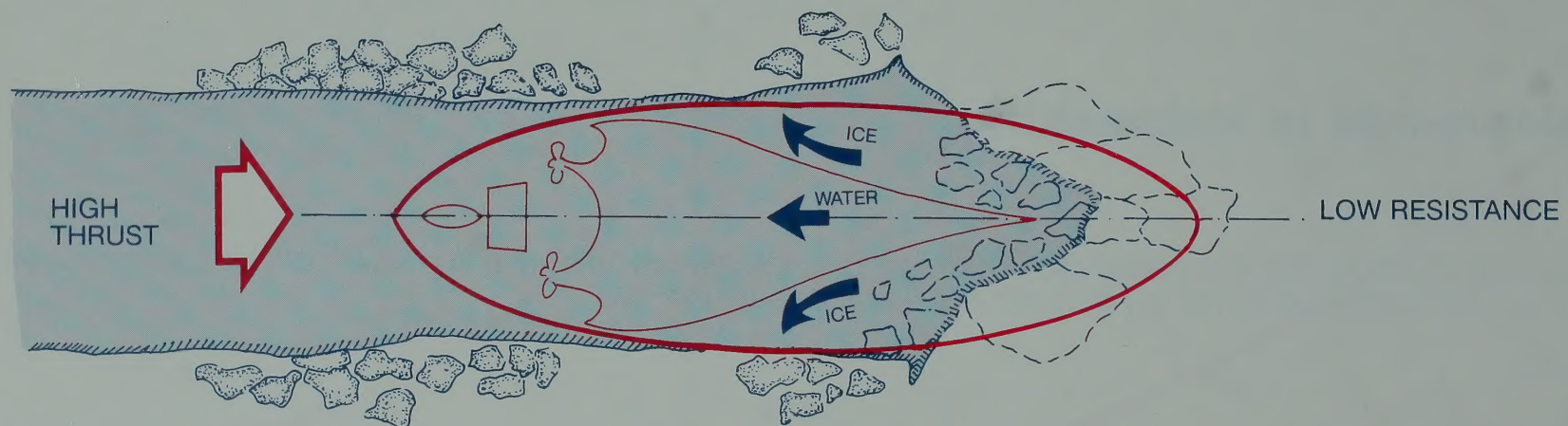


FIGURE 4: GOOD PERFORMANCE IN LEVEL ICE.

IN THICK LEVEL ICE OVER 40% OF THE TOTAL RESISTANCE IS DUE TO THE BREAKING PHENOMENON. THE MOST IMPORTANT FACTOR IS THE PSII ANGLE, THAT IS THE ANGLE BETWEEN A VERTICAL VECTOR AND A NORMAL TO THE HULL PLATING IN THE WATERLINE AREA. THE PSII ANGLE CAN BE MINIMIZED BY A CYLINDRICAL (OR SPOON) BOW FORM OR BY USING A LANDING CRAFT BOW. A CYLINDER SHAPE HAS BEEN ADOPTED IN CANADA IN THE SUPPLY VESSELS CANMAR KIGORIAK AND ROBERT LEMEUR AND IN FINLAND IN THE 2.5 METER DRAFT ICEBREAKER OF THE EVDOKIMOV TYPE. LANDING CRAFT ICEBREAKING AND CLEARING BOWS, KNOWN AS LPPS AND LLP, HAVE BEEN USED SUCCESSFULLY ON THE SOVIET RIVERS FOR MANY YEARS. THE GERMAN INNOVATION, THE WAAS BOW, IS ALSO CLEARLY A LANDING CRAFT BOW. ACCORDING TO OUR MODEL TESTS, THE RESISTANCE WITH A CYLINDRICAL BOW IS SMALLER THAN THAT WITH A LANDING CRAFT BOW IF THE STEM ANGLE IS THE SAME.

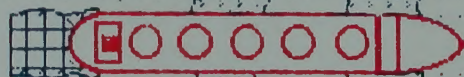
HIGH THRUST CAN SOMETIMES BE ACHIEVED BY USING DUCTED PROPELLERS. THE ICE HAS THEN TO BE TRANSFERRED TO THE SIDES, TO AVOID CLOGGING OF THE NOZZLES WITH BROKEN ICE. THE ICE IS MOVED EITHER ACTIVELY WITH A MECHANICAL PLOW OR PASSIVELY BY EXPLOITING THE BUOYANCY OF THE ICE. THE PLOW SOLUTION HAS BEEN USED IN ROBERT LEMEUR AND WITH THE LPS AND LLP. IT HAS ALSO BEEN TESTED SUCCESSFULLY BY WÄRTSILÄ IN 1985 IN A NEW EXPERIMENTAL BOW. THE BUOYANCY METHOD NEEDS A DISTINCT RISE OF FLOOR. IT HAS BEEN USED IN CANMAR KIGORIAK AND ITS EFFECT HAS BEEN ENHANCED WITH THE AIR BUBBLER SYSTEM IN THE NEW ICEBREAKER OTSO.

GOOD MANEUVERABILITY IS NEEDED IN ESCORT OPERATIONS. THE VESSEL SHOULD BE CAPABLE OF BACKING AND TURNING IN THICK ICE. THE ABILITY TO BACK DEPENDS ON THE PROPELLER AND RUDDER CONFIGURATION AND FURTHER ON THE RUDDER ARRANGEMENT, LENGTH/BREADTH RATIO AND HULL FORM.

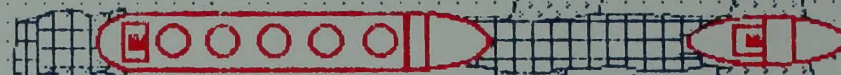
## ESCORT ICEBREAKER SUPPORT ACTIVITIES



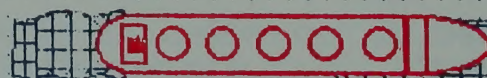
PUSHING A TANKER  
THROUGH A RIDGE



FREEING A TANKER  
STUCK IN THE ICE



BREAKING A PATH  
OF REDUCED RESISTANCE



MANEUVERING  
ASSISTANCE

FIGURE 5: ESCORT ICEBREAKER SUPPORT ACTIVITIES.

## The escort icebreaker

THE ICEBREAKER HAS TO BE CONSIDERED AS A WHOLE AND TO BE SUITED IN ALL RESPECTS FOR THE TASK FOR WHICH IT IS INTENDED. THE STARTING POINT IS THE ABILITY TO PROCEED THROUGH ICE, BUT THE ESCORT ICEBREAKER ALSO HAS TO BE:

- RELIABLE, BEING A VITAL PART OF AN EXPENSIVE SYSTEM, IN WHICH NO UNPROVEN TECHNOLOGY IS DESIRED.
- ECONOMICAL, BEING A COMPANY-OWNED ICEBREAKER, WHICH MUST CONTRIBUTE TO THE PROFITABILITY OF THE OPERATIONS.

FOR LOW RESISTANCE, A CYLINDRICAL BOW WAS SELECTED. THERE MAY BE SOME SLAMMING IN WAVES, BUT THE ICEBREAKER WILL OPERATE ALMOST ENTIRELY IN ICE-COVERED WATERS. LOW FRICTION WILL BE ACHIEVED WITH STAINLESS STEEL PLATING IN THE WATERLINE AREA AND LOW-FRICTION PAINT BELOW.

LACK OF RELIABILITY IN HIGH-POWERED ICEBREAKERS HAS BEEN DUE TO PROPELLER PROBLEMS. TO AVOID THESE AND TO GAIN GOOD PERFORMANCE WHEN BACKING, ELECTRICAL PROPULSION WAS CHOSEN.

FOR HIGH THRUST, A THREE PROPELLER SOLUTION WITH A BIG DUCTED CENTER PROPELLER WAS SELECTED. THE CENTER PROPELLER ABSORBS 50% OF THE POWER AND THE SIDE PROPELLERS 25%. THE OPEN SIDE PROPELLERS ARE QUITE SMALL AND ARE SITUATED FAR DOWN, TO MINIMIZE ICE MILLING. CLOGGING OF THE 8 METER DIAMETER CENTER PROPELLER WILL BE RARE, DUE TO ITS POSITION AND THE PROGRESSIVE LINES OF THE VESSEL. A MECHANICAL PLOW UNDER THE BOTTOM AND THE RISE OF FLOOR SOLUTION WERE SELECTED TO PREVENT BROKEN ICE FROM ENTERING THE PROPELLER AREA.

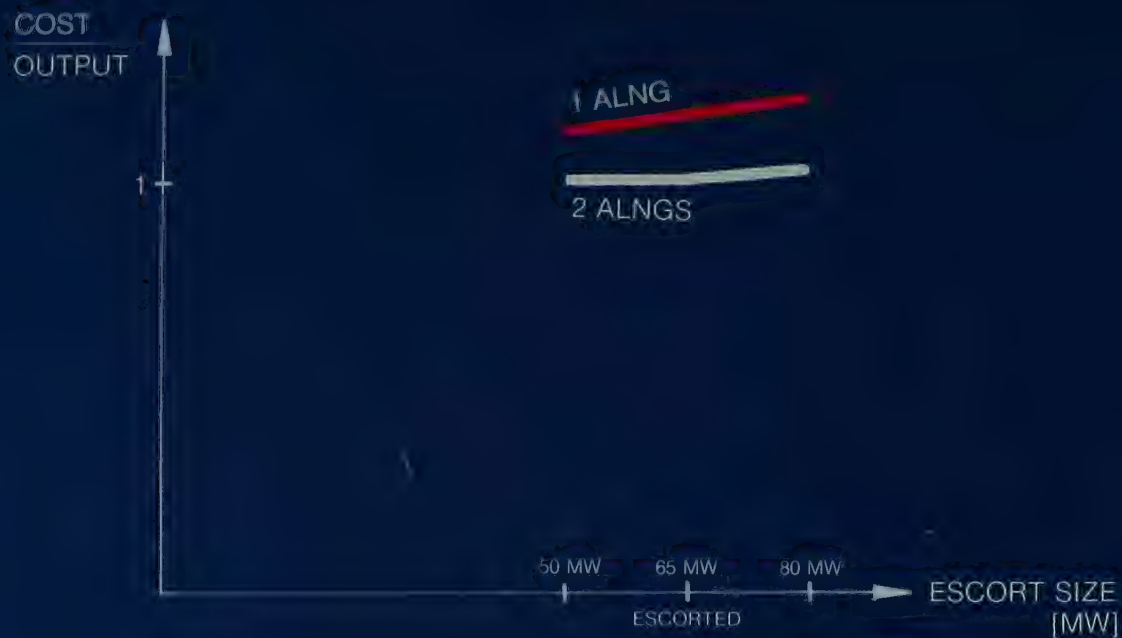


FIGURE 6: TOTAL MARINE ECONOMY CONTRA ESCORT VESSEL SIZE.

A HIGH-POWER AIR BUBBLING SYSTEM WILL INTENSIFY THE ICE-CLEARING. THE AIR BUBBLING SYSTEM IS AN ACTIVE SYSTEM AND ITS EFFICIENCY WILL INCREASE WHEN THE VESSEL LOSES SPEED IN THICK ICE; WHEN THE SPEED DROPS, THE BUBBLING SYSTEM WILL HAVE MORE TIME TO TRANSFER THE ICE TO THE SIDES.

THE MOST IMPORTANT ECONOMIC PARAMETER IS THE VESSEL SIZE. THIS WAS INVESTIGATED USING THREE DIFFERENT POWERS: 50 MW (68,000 hp), 65 MW (88,000 hp) AND 80 MW (108,000 hp).

THE MAIN DIMENSIONS WERE SELECTED FOR THE THREE DESIGNS AND THEIR PERFORMANCE WAS EVALUATED WITH A COMPUTER TRANSIT SIMULATION PROGRAM. THE AVERAGE SPEED WAS THEN USED IN A TOTAL ECONOMY PROGRAM, TO EVALUATE THE MARINE TRANSPORTATION COST FOR A SYSTEM CONSISTING OF ONE ESCORT ICEBREAKER AND ONE OR TWO ALNGS. THE RESULTS ARE SHOWN IN FIGURE 6, BUT THEY ARE RATHER INCONCLUSIVE.

HIGHER POWER LEADS TO INCREASED GAS OUTPUT, BUT THIS IS BALANCED BY BIGGER CAPITAL COSTS FOR THE ESCORT ICEBREAKER.

A 65 MW (88,000 hp) SHAFT POWER SOLUTION WAS CHOSEN BECAUSE IT ENABLED THE ABOVE-DESCRIBED PROPELLER ARRANGEMENT WITH RELATIVELY SMALL SIDE PROPELLERS (6 METER DIAMETER). THE HIGHER-POWERED ALTERNATIVE WOULD HAVE HAD THREE EQUALLY POWERED PROPELLERS WITH POORER BACKING ABILITY.

THE PRIME POWER GENERATORS CONSIDERED WERE GAS TURBINES AND DIESEL ENGINES. DIESELS ARE HEAVIER, BUT DEMAND LESS FUEL, AS THE CONSUMPTION RATE IS LOWER. CALCULATIONS REVEALED THAT THE WEIGHT DIFFERENCES CANCELED EACH OTHER OUT AND THERE WAS NO SIGNIFICANT PRICE DIFFERENCE EITHER. THE GAS TURBINE ALTERNATIVE WAS CHOSEN BECAUSE IT IS VERY RELIABLE, HAS FEW MOVING PARTS AND NEEDS LITTLE MAINTENANCE. THE POWER IS GENERATED WITH FOUR UNITS. THE ELECTRICAL SYSTEM IS A MODERN AC-CYCLOCONVERTER CONTROLLED VARIABLE FREQUENCY-AC POWER PLANT SYSTEM. AC PROPELLER MOTORS ARE MORE COMPACT AND NEED LESS MAINTENANCE THAN DC PROPELLER MOTORS.

LIQUEFIED NATURAL GAS WILL BE USED AS FUEL. THIS WILL IMPROVE THE PROFITABILITY, AS THE OPERATOR CAN OBTAIN THE FUEL AT A MODERATE PRICE. IT IS ALSO PRACTICAL AS THE ALNGS CAN REFUEL THE ESCORT ICEBREAKER. THE FUEL IS STORED IN TWO SPHERICAL TANKS, EACH HAVING A DIAMETER OF 23 m AND A CAPACITY OF 6,000 m<sup>3</sup>.

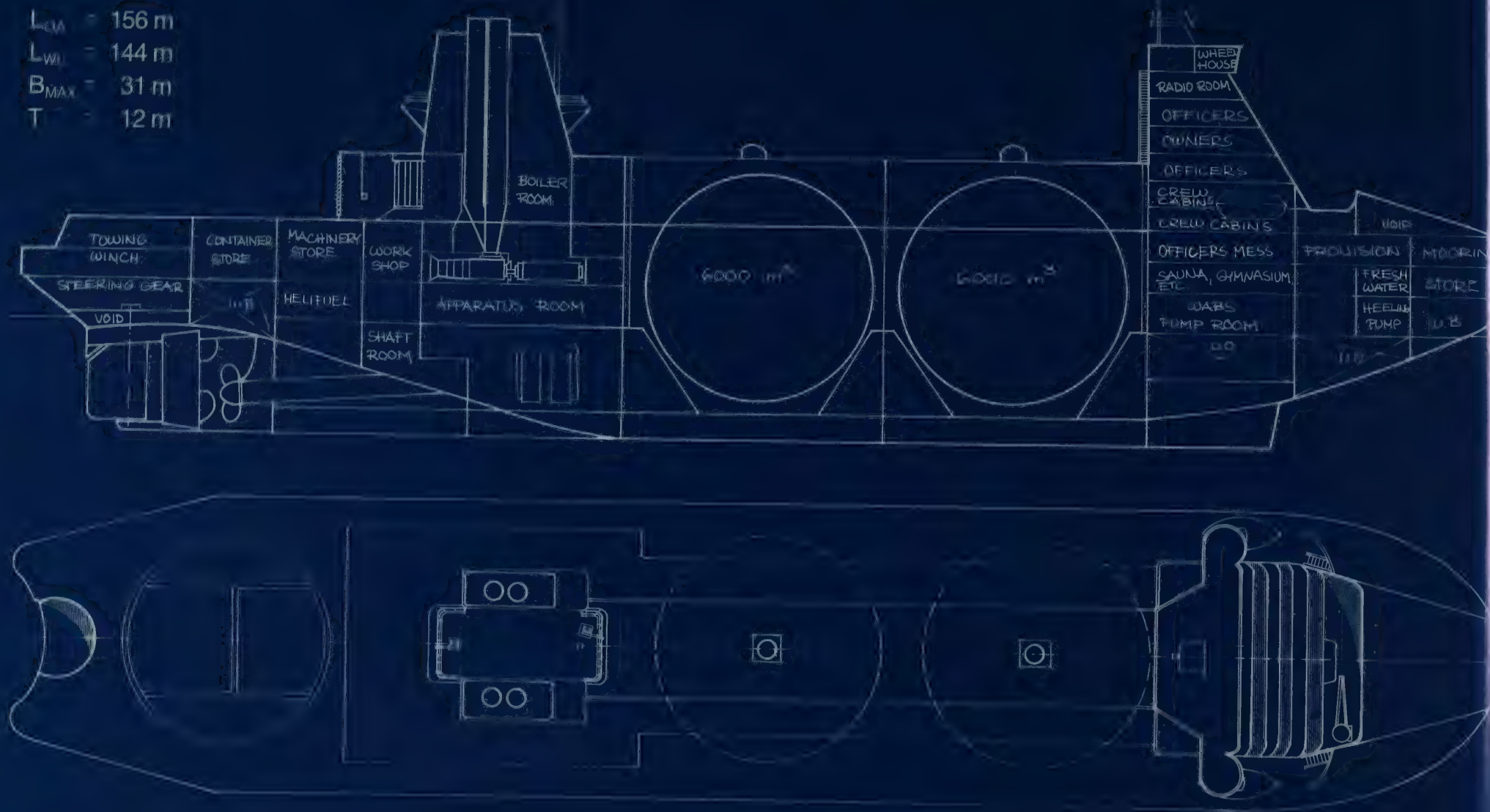


FIGURE 7: GENERAL ARRANGEMENT.

THE GENERAL ARRANGEMENT IS SHOWN IN FIGURE 7. IT UTILIZES A MODULAR-BASED SHIP DESIGN CONCEPT, IN WHICH RELATED ITEMS ARE CONCENTRATED IN THE SAME AREA. THIS GIVES A STRAIGHTFORWARD SOLUTION FOR EASIER MAINTENANCE AND A SHORTER BUILDING TIME.

THE MIDSHIP AREA IS DOMINATED BY THE BIG FUEL TANKS. THE ACCOMMODATION AREA IS SITUATED FORWARD OF THE FUEL TANKS. THE CREW HAVE SPACIOUS SINGLE CABINS IN THE SUPERSTRUCTURE.

A SAUNA, GYMNASIUM AND SQUASH HALL ARE SITUATED BELOW IN THE HULL, WHERE THERE IS MORE NOISE AND VIBRATION FROM THE ICEBREAKING. ALL SHIP AREAS CAN BE REACHED THROUGH COVERED AND HEATED CORRIDORS, TO ENABLE EFFICIENT WORK IN COLD ARCTIC CONDITIONS. THE MOORING DECKS ARE ALSO COVERED, TO PREVENT ICING OF THE MOORING EQUIPMENT.

THE COMPACT POWER PACKAGE IS SITUATED BEHIND THE FUEL TANKS. THE GAS TURBINE AND GENERATORS ARE LOCATED ON THE MAIN DECK. BELOW IS THE APPARATUS ROOM FOR CURRENT FREQUENCY MODULATION. THE PROPELLER MOTORS ARE LOCATED DIRECTLY BELOW THIS ROOM, TO ALLOW SHORT HIGH POWER LINES. THE MODERN ELECTRICAL PROPULSION SYSTEM REDUCES THE LENGTH OF THE MACHINE ROOM, AS THE UNITS CAN BE STACKED VERTICALLY.

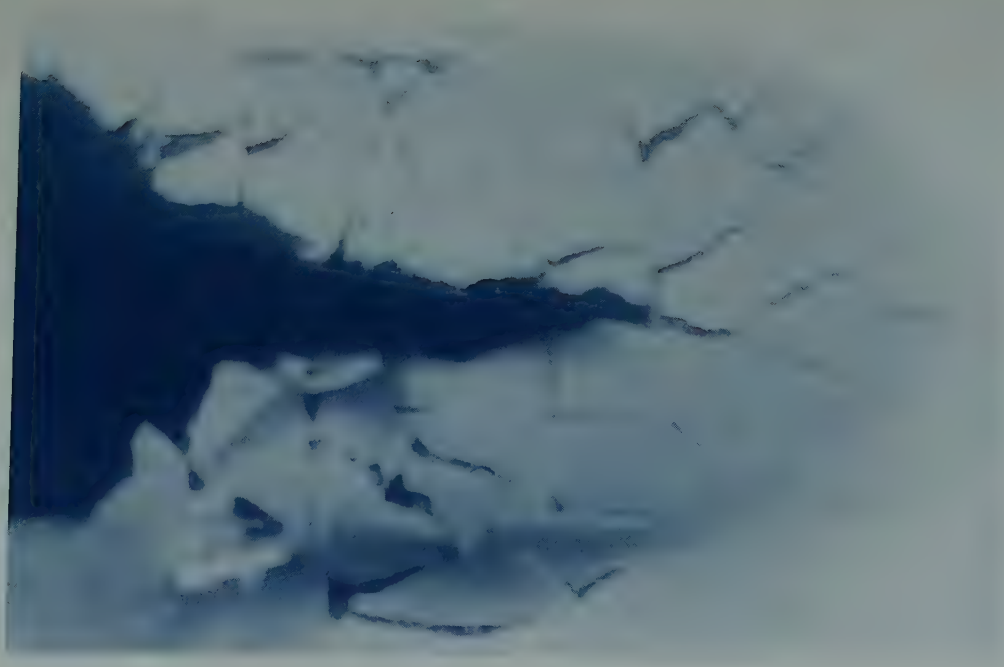


FIGURE 8: MODEL BREAKING 2 m THICK ICE.



FIGURE 9: MODEL BACKING IN LEVEL ICE.

## Performance

THE NEW ICEBREAKING VESSELS ARE MODEL-TESTED, TO CHECK THAT THEY WILL BEHAVE AS EXPECTED AND TO DETERMINE THEIR PERFORMANCE CAPABILITY. THE ESCORT ICEBREAKER WAS ESTIMATED TO BE CAPABLE OF BREAKING LEVEL ICE 3 METERS THICK, WHEN OPERATING IN THE CONTINUOUS MODE OF ICEBREAKING. THE MODEL TESTS WERE, HOWEVER, PERFORMED IN SCALED THICKNESSES OF 1 AND 2 METERS, AS THICKER LEVEL ICE IS RATHER RARE.

TESTS WERE PERFORMED IN LEVEL ICE, FLOE ICE AND RIDGED ICE. FIGURE 8 SHOWS THE SCALED MODEL BREAKING 2 m THICK LEVEL ICE. ACCORDING TO THE TESTS, THE RESISTANCE ENCOUNTERED BY THE VESSEL IS 35 % LOWER THAN THE RESISTANCE TO A CONVENTIONAL WEDGE-SHAPED BOW.

A SPEED OF 6.5 knots SHOULD BE ACHIEVED IN 2 m THICK ICE. TESTS IN RIDGES WERE DONE TO EVALUATE THE PROPULSION PERFORMANCE IN HEAVY ICE CONDITIONS. THE RESULTS WERE SATISFACTORY; THE CENTER NOZZLE NEVER BECAME CLOGGED, ALTHOUGH SOME ICE WAS SUCKED THROUGH IT. THERE WAS NO DIFFICULTY EITHER IN BACKING IN LEVEL ICE, BECAUSE THE ICE MOVED NEATLY OVER THE NOZZLE, AS SHOWN IN FIGURE 9.

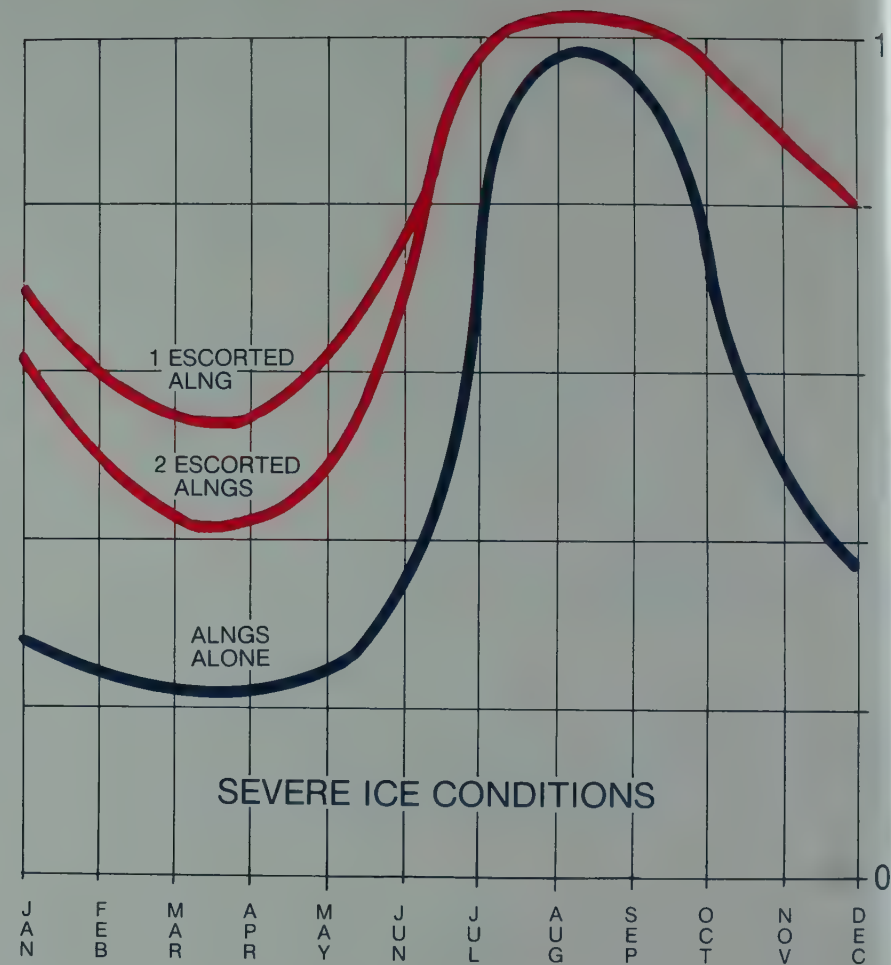
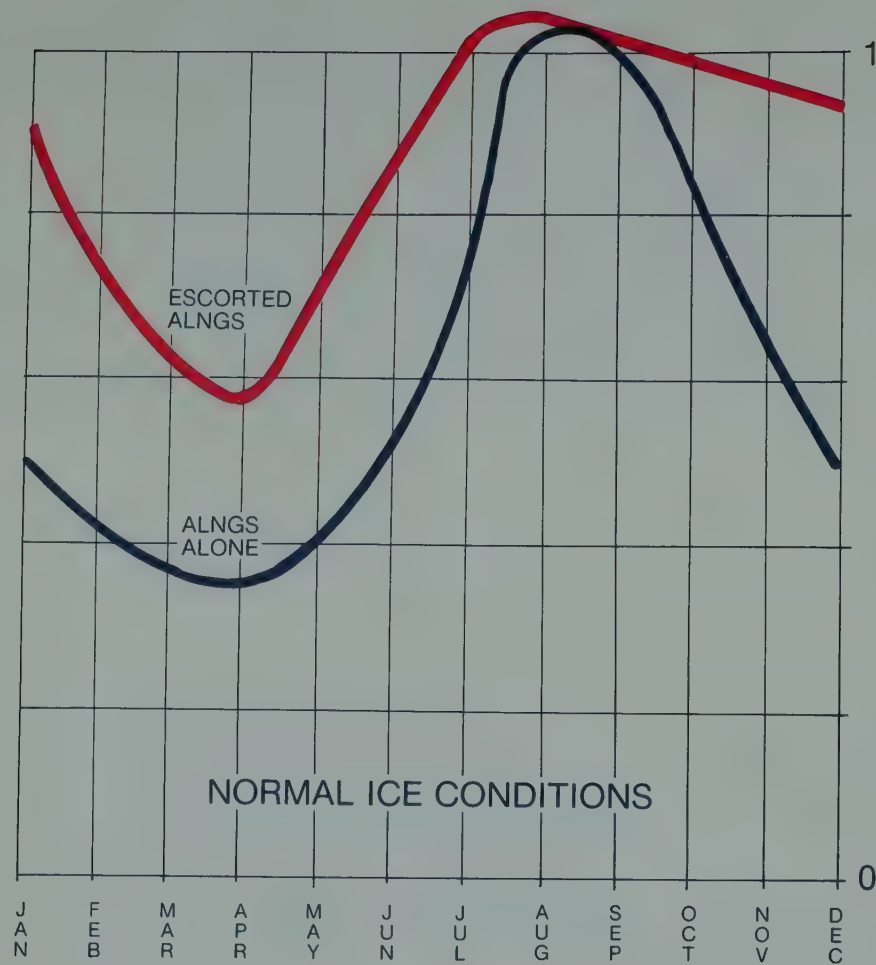


FIGURE 10: VOLUME TRANSPORTED/TANKER OPERATING THROUGHOUT THE YEAR.

THE PERFORMANCE VALUES WERE USED AS INPUT IN A COMPUTER PROGRAM SIMULATING THE SPEED OF THE ESCORT ICEBREAKER IN REAL ICE CONDITIONS. THE SAME PROGRAM WAS RUN TO EVALUATE THE SPEED OF THE ALNGS OPERATING ALONE. THE PERFORMANCE OF THE SHIPS WAS SIMULATED IN BOTH NORMAL AND SEVERE ICE CONDITIONS TO EVALUATE THE SENSITIVITY OF THE TRANSPORTATION TO CHANGING WEATHER CONDITIONS. ONE ESCORT ICEBREAKER ASSISTING TWO ALNGS WAS ALSO CONSIDERED, TO STUDY A CASE WITH GREATER OUTPUT.

THE SIMULATION CALCULATIONS GIVE THE OUTPUT OF TRANSPORTED GAS FOR THE DIFFERENT VESSEL CONFIGURATIONS. THESE RESULTS ARE SHOWN IN FIGURE 10.

THE USE OF AN ESCORT VESSEL CLEARLY IMPROVES THE OUTPUT. IN SEVERE ICE YEARS, THE OUTPUT WITH AN UNASSISTED ALNGS WILL STOP ALMOST COMPLETELY IN THE WINTER. WHEN THE ALNGS IS ASSISTED, THE WINTER OUTPUT WILL BE 40% LOWER THAN THE SUMMER OUTPUT.

THE SIMULATIONS ALSO REVEAL THAT ONE ESCORT ICEBREAKER CAN ASSIST TWO ALNGS ALMOST AS EFFECTIVELY AS ONE ALNGS IN NORMAL YEARS. THIS IS BECAUSE ONE ALNGS CAN OPERATE INDEPENDENTLY IN THE SOUTHERN PARTS OF THE ROUTE WHILE THE OTHER IS ASSISTED THROUGH THE MORE SEVERE CONDITIONS IN THE BEAUFORT SEA.

## MARINE TRANSPORTATION

## PRUDHOE BAY — ADAK

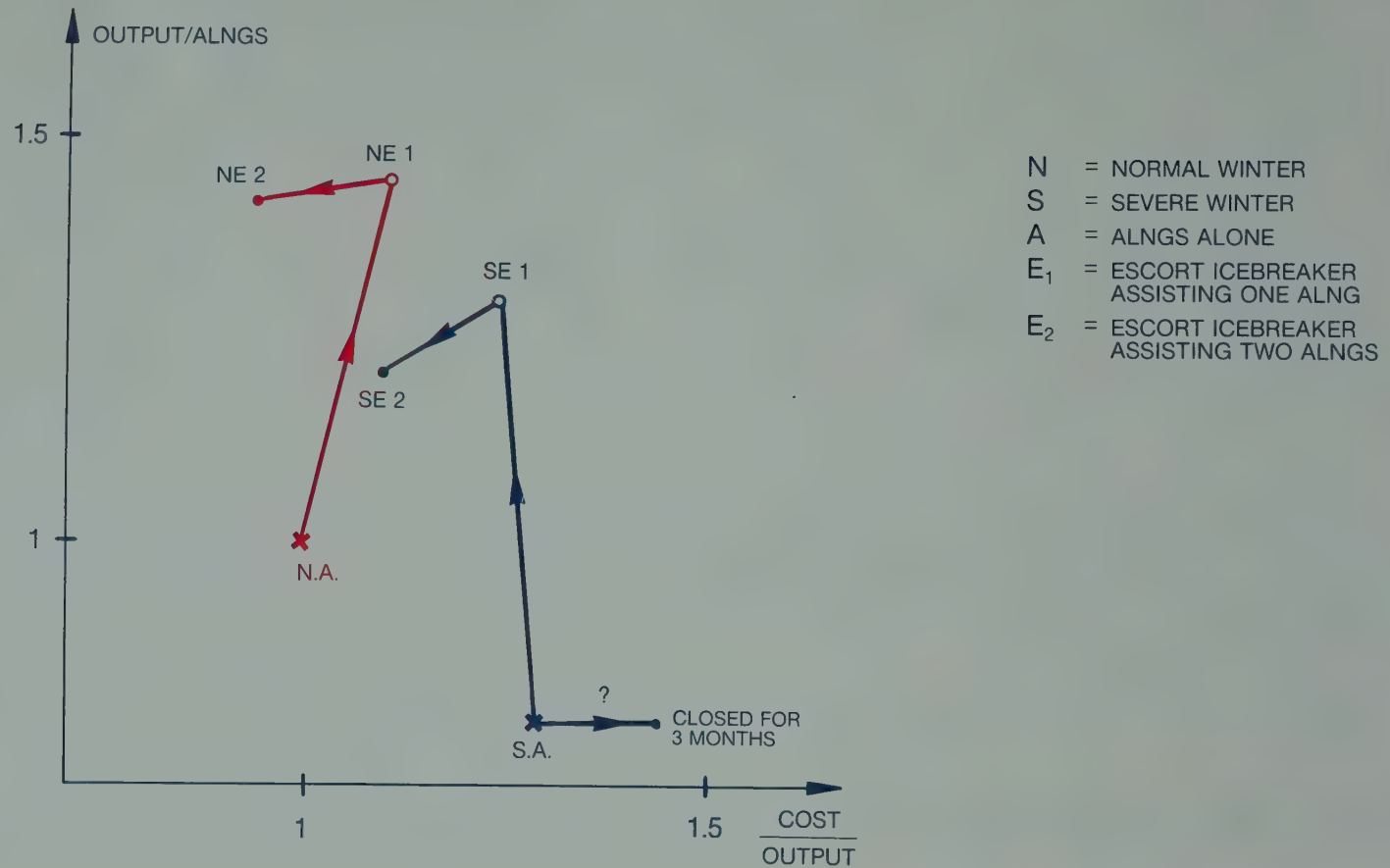


FIGURE 11: TRANSPORTATION COSTS FOR DIFFERENT MARINE FLEETS.

## Economics

A TOTAL ECONOMY COMPUTER PROGRAM WAS RUN TO CHECK THE ECONOMIC FEASIBILITY OF ICEBREAKER-ASSISTED MARINE OPERATION. ICEBREAKER ASSISTANCE IS NORMALLY PROVIDED BY A GOVERNMENT, BUT IN THIS CASE IT WAS ASSUMED THAT THE TANKER SHIP OPERATOR WOULD ALSO BEAR THE COSTS OF ICEBREAKER ASSISTANCE.

THE INCOME, OR TRANSPORTED GAS VOLUME, WAS CALCULATED FROM THE TRANSIT SIMULATIONS. THE MAIN COSTS ARE THE INVESTMENT IN THE SHIPS AND THE EXPENSES OF THE FUEL AND THE CREW. THE FUEL COSTS ARE FAIRLY LOW AS NATURAL GAS IS INEXPENSIVE FOR THE OPERATOR. THE CREW COSTS ARE ALSO RELATIVELY SMALL AS THESE MODERN VESSELS CAN BE OPERATED BY A CREW OF ONLY 30 PERSONS. THE VESSELS THEMSELVES ARE EXPENSIVE, AS THEY ARE HIGH-POWERED VERY SPECIALIZED ICE-GOING VESSELS. THE CAPITAL COSTS ARE THEREFORE HIGH AND MAKE UP ABOUT 60% OF THE TOTAL COSTS.

FIGURE 11 SHOWS OUTPUT AND RELATIVE COST. THE USE OF AN ESCORT VESSEL WILL GIVE CONSIDERABLY GREATER OUTPUT AT ONLY SLIGHTLY INCREASED COST. IF THE ESCORT ASSISTS TWO ALNGS, THE OUTPUT IS INCREASED AND THE COST LEVEL REDUCED. THIS IS DUE TO THE FACT THAT THE CAPITAL COST OF THE ICEBREAKER CAN BE SHARED BETWEEN THE TWO ALNGS. THESE CALCULATIONS INCLUDE ONLY MARINE SYSTEM COSTS. IF SOME OF THE COSTS OF THE HARBOUR AND LIQUEFACTION PLANT ARE INCLUDED, THEN THE USE OF AN ESCORT IS EVEN MORE PROFITABLE.



FIGURE 12: ARTIST'S IMPRESSION OF THE ESCORT ICEBREAKER ASSISTING ALNGS IN THE HIGH ARCTIC.

COMPARED WITH THE CLASSICAL ICEBREAKER, CHANGES HAVE BEEN MADE IN THE HULL SHAPE AND PROPULSION ARRANGEMENT. MODERN DEVELOPMENTS IN THE ART OF ICE NAVIGATION SHOW THAT RESISTANCE CAN BE REDUCED AND PROPULSION IN ICE IMPROVED. THE FUEL SELECTED, LIQUEFIED NATURAL GAS, AFFECTS THE GENERAL ARRANGEMENT CONSIDERABLY, AS SPACE HAS TO BE PROVIDED FOR TWO BIG SPHERICAL TANKS. NO OTHER SERIOUS DISADVANTAGES WERE IDENTIFIED WITH COLD ( $-163^{\circ}\text{C}$ ) FUEL.

LARGE FUEL CAPACITY IS NECESSARY, HOWEVER, IN AN ICEBREAKER OPERATING FAR AWAY FROM REFUELING FACILITIES. THE WEIGHT OF THE FUEL REQUIRED FOR A LARGE ICEBREAKER IS CONSIDERABLE, OVER 8,000 tons FOR THE 65 MW (88,000 hp) ESCORT ICEBREAKER, WHICH CAN OPERATE AT FULL POWER FOR OVER 20 DAYS. ATTEMPTS TO DESIGN POLAR ICEBREAKERS WITH EVEN GREATER ENDURANCE EASILY RESULT IN MEDIUM-SIZED ICEBREAKING TANKERS.

THE TECHNICALLY CORRECT MACHINERY SOLUTION FOR THE ESCORT ICEBREAKER IS THEREFORE NUCLEAR POWER, AS INFINITE ENDURANCE COULD BE ACHIEVED WITH A SMALLER ICEBREAKER. THE PROBLEM WITH NUCLEAR POWER IS THE INCREASED CAPITAL COST AND IN THIS DESIGN CASE GAS TURBINE POWER IS CLEARLY ECONOMICAL, AS THE FUEL IS RATHER INEXPENSIVE.

OUR CONCLUSION IS THAT RELIABLE AND EFFICIENT HIGH-POWERED ARCTIC ICEBREAKERS ARE BOTH TECHNICALLY FEASIBLE AND ECONOMICAL. FIGURE 12 CLEARLY DEMONSTRATES THAT THEIR DESIGN IS NOT ONLY SCIENCE BUT ALSO A FINE ART.

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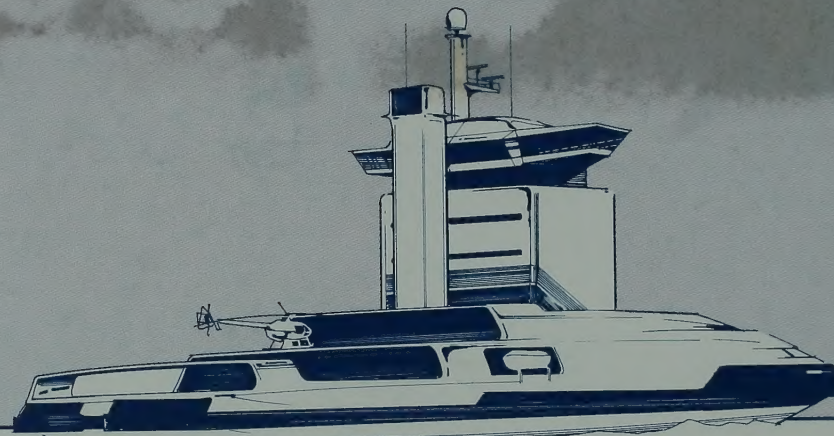
  

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